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A New Method of Evaluating Microcellular System Capacity Using Deterministic Propagation Models

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Abstract

Site specific planning tools will become increasingly important as microcellular communication systems continue to evolve. These tools will enable system planners to design their systems far more rapidly and to minimise the cost of their development. In this paper, a new method for microcellular system capacity evaluation is presented, which proposes the use of the site specific ray-tracing propagation models developed at the University of Bristol. The propagation model includes the effects of urban shielding & shadowing in site specific environments.

To simplify the processing procedure, a statistical propagation model is used to generate the signal coverage of a Rayleigh fading environment. Taking into account the particular system requirements, such as the modulation scheme, BER and outage probability, the propagation results for a given area can be extensively analysed to produce its system capacity. Obviously, site specific propagation coverage will provide a more accurate estimation of system capacity.

I. INTRODUCTION

The concept of a microcell has been introduced into cellular networks to provide increased capacity within a limited radio spectrum allocation. Although microcells are not formally defined, they generally refer to small cells (<1km) in an urban area where the base station antennas are significantly lower than the surrounding roof tops. Therefore, unlike conventional large cell scenarios, where base station antennas are often placed on the tallest building, a microcells' coverage area is largely governed by the effects of surrounding buildings (urban shielding). Microcells also operate using lower transmit power at the base station, and this will further reduce the coverage area. The lower transmit power combined with the effects of urban shielding result in a shorter reuse distance, hence cell frequencies can be reused more often in a given area.

A high density of reuse cells will naturally increase system capacity.

Several authors[1][2] have studied the impact of cellular network capacity in an interference limited system. These studies randomly located many users in a cell until the outage Cumulative Distribution Function (CDF) exceeded a required threshold. The propagation information was based on statistical models. However, unlike previous large cell scenarios, statistical models can no longer provide acceptable results in a microcell due to the site specific nature of the environment. For microcellular studies, the propagation models should take into account the exact position of each individual building. The developed capacity evaluation model will enable system designers to consider the impact of shielding and shadowing effects in the planning of future microcellular networks.

In this paper, it is proposed that in a cochannel interference limited environment, the capacity can be deterministically evaluated by studying the effective coverage area of each individual cell. The propagation coverage for each cell site can be obtained by using deterministic ray-tracing techniques.

In a cochannel interference limited cellular system, each cell is surrounded by many reuse cells. There are six reuse cells in the first tier and twelve reuse cells in the second tier, this is true regardless of the reuse pattern. The first tier of reuse cells are the major source of cochannel interference[7]. In practice, all cochannel cells in urban areas show very similar characteristics in terms of signal variation versus coverage area. Therefore, an average signal behaviour for the cochannel cells can be derived. When system BER & system outage probabilities are applied, an average reuse distance can be obtained for the type of environment being considered. This enables the capacity to be accurately estimated in terms of channels/MHz/km².

To further explain this new method of capacity evaluation, two essential modelling processes will be presented,

namely radio propagation coverage prediction and capacity assessment.

II. PROPAGATION MODEL

The proposed propagation model for obtaining our coverage prediction is based on the concept of ray-tracing. In dense urban environments the radio signal is strongly influenced by surrounding buildings. Ray models can base their signal prediction on site specific building database information. The model assumes that walls in each microcell are infinitely tall, this assumption is normally valid since microcells have base stations and mobiles below the surrounding building roof tops. Walls are assumed to be perpendicular to the ground but not necessarily to each other, the ground is flat. These limitations are acceptable for most urban microcellular environments[3].

Each wall is characterised by its permittivity, conductivity, and thickness. Wall thickness is required in the calculation of the reflected and transmitted field strength. The reflection and transmission coefficients are evaluated as a function of incident angle for a range of different wall materials. The equations used to calculate the received signal energy have been presented by [3][4][5] as:

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2} \left[\prod_j R_j \right] \left[\prod_l T_l \right] \left[\prod_k A_k(s', s) D_k \right]^2 \quad (1)$$

where P_t represents the transmitter power, d is the total length of the ray path, λ is the wavelength, G_t and G_r are the transmitting and receiving antenna gains in the direction of each ray, R_j is the angle dependent reflection coefficient for the j^{th} path, T_l is the angle dependent wall transmission coefficient for the l^{th} transmission and D_k the diffraction coefficient for the k^{th} diffracting wedge. The diffraction coefficients are also multiplied by a spatial attenuation function $A_k(s', s)$ which finds the correct multiplicative diffraction coefficient given the $1/d^2$ dependence in the first term.

III. EFFECTS OF MODULATION, BER & OUTAGE PROBABILITY

In a cochannel interference limited mobile radio system, adequate signal strength and signal to interference ratios (SIR) are essential for successful communications. Outage probability, defined as the probability of failing to simultaneously achieve a signal to noise ratio (SNR) and a signal to interference ratio sufficient to give satisfactory reception, is an appropriate measure for evaluating the performance of mobile radio systems[6].

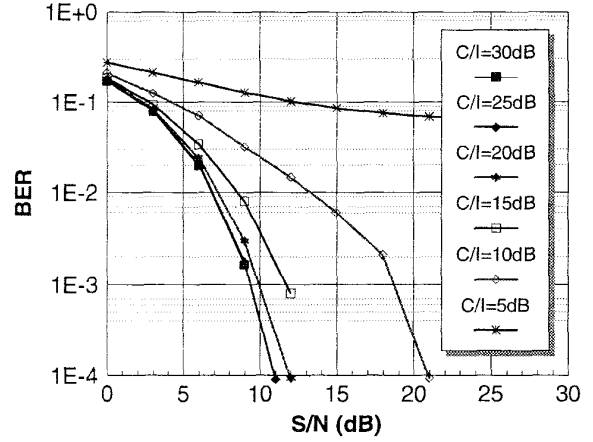


Figure 1. BER v S/N In the presence of Cochannel Interference

Fig. 1 shows the result of a system simulation using differential QPSK. In the presence of cochannel interference and AWGN noise, it clearly shows that for a required BER and a required cochannel interference ratio, the signal to noise ratio can be determined. If the transmit power is reduced, a higher cochannel interference ratio must be used to achieve the required system BER. These parameters are generally considered as fundamental factors in mobile radio system design and will be used in the subsequent capacity evaluation.

IV. DETERMINATION OF SYSTEM REUSE DISTANCE

The system reuse distance is referred to as the average reuse distance in a microcellular network where the same frequency channels are in use. Naturally, in microcellular network planning, when the channel occupancy and teletraffic density are uniform, more reuse cells equate to a higher capacity. Therefore, the accurate prediction of the average reuse distance can result in an enhanced and more cost effective cellular design.

The method for evaluating the system average reuse distance is divided into two steps. The first step assumes the system is noise limited and cochannel interference is ignored. Cell signal coverage for a given transmit power can be obtained using the ray tracing model described earlier. However, in this paper preliminary results will be presented based on a statistical $1/d^2$ Rayleigh model.

Fig 2 shows the average statistical propagation path loss in all directions around the base station as the mobile moves away from the base site. The average cell radii is defined as the distance from the base site, within which the required Signal to Noise ratio and outage probability are

maintained. Thus, in this case, the average cell radii has been found to be 530m as shown in Fig. 2, assuming the minimum received signal power is -115dBm. The noise considered in this study is Additive White Gaussian Noise.

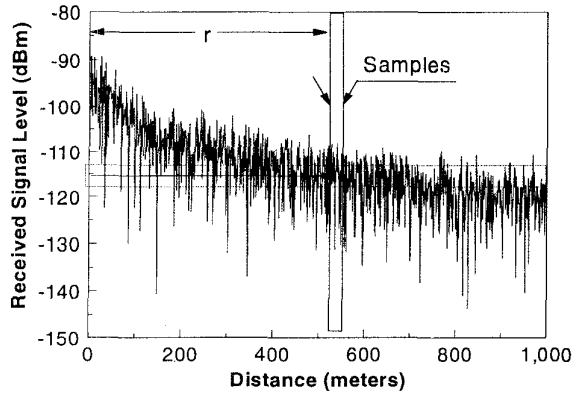


Figure 2. Average Propagation Path loss

When cochannel cells exist, the system becomes interference limited. The minimum distance which allows the same frequency to be reused will depend on many factors, such as the number of cochannel cells in the vicinity of the centre cell, the type of geographic terrain, the antenna height, antennas pattern and the transmit power at each base site. In this paper, the technique presented for evaluating the minimum reuse distance can include all these factors.

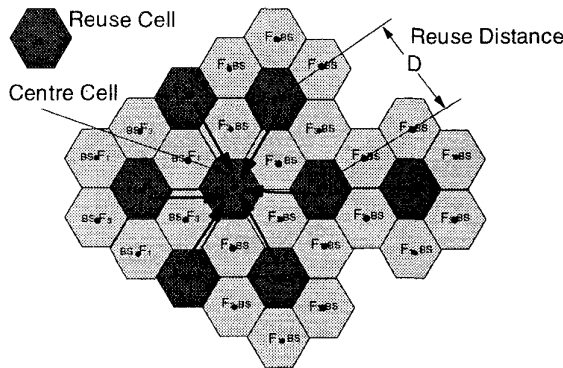


Figure 3. Cochannel Interference Contribution

Fig. 3 shows a three cell reuse pattern, where each cochannel cell is highlighted by the darker shading. The first tier consists of six cochannel cells. It is practical to assume that the cochannel interference is mainly contributed by the first tier of cochannel cells[7]. This allows the cochannel interference to be modelled as the total contribution of six cochannel cells. The study shows

that in the same urban environment, the signal path loss shows very similar characteristics in each cell. Thus the cochannel pathloss characteristics of each interferer can be duplicated from the statistics of the centre cell. Fig. 4 shows the situation with cochannel interference.

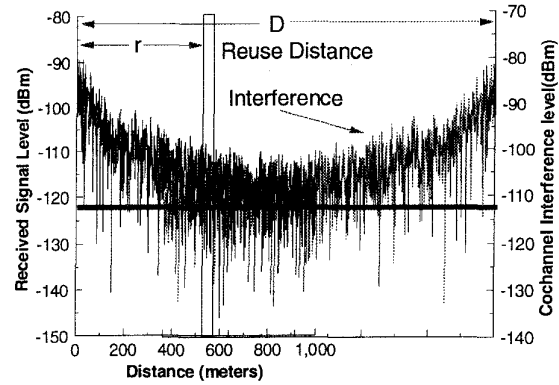


Figure 4. Determination Of Average Reuse Distance

With reference to the required signal to interference ratio and outage probability, the six cochannel cells can be moved towards the centre cell as shown in Fig 4. This diagram shows the received signal level in contrast to the received cochannel interference level as the cochannel cells are moved towards the centre cell. In this process, the defined signal to interference ratio and outage probability will eventually be satisfied at a point corresponding to the minimum reuse distance.

The evaluated minimum reuse distance can be regarded as an average reuse distance of a defined cluster area. With the evaluated average system radii from the previous section, it is now possible to calculate the capacity of the microcellular system.

V. CAPACITY EVALUATION TECHNIQUES

The microcellular system capacity can be described using Erlangs per Km², so long as each cell traffic condition and channel allocation are defined. The spectral efficiency of the system is defined as[7]

$$\eta_s = \frac{\text{Total number of channels available}}{\text{Total BW available} \times \text{cluster area}}$$

thus the spectral efficiency can be expressed as *Channels per MHz per kilometre squared*. Therefore, to calculate the spectral efficiency, the cell planning pattern must be identified in a cluster area. Taking results from the previous sections, the reuse cell pattern can be planned, as

shown in Fig. 5. The cluster size k is derived using Lee's[7] equation $k = D^2 / 3r^2$, where D represents reuse distance and r the cell radius.

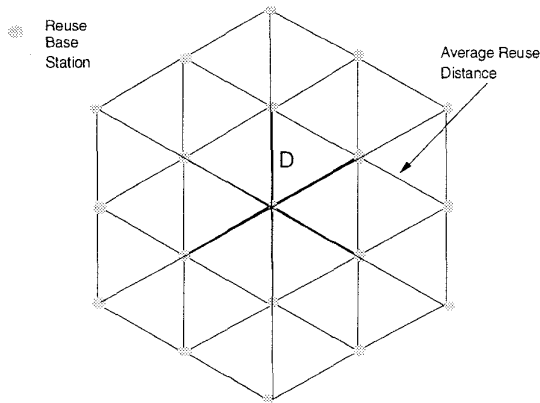


Figure 5. Optimum Reuse cell Pattern in a Cluster area

Fig 5. shows that the optimum reuse pattern can now be planned in a given area. This concept can be used as a realistic approach for planning the reuse pattern in microcellular networks. Because the average cell radii is a known factor derived from Fig. 2, the total number of cells allowed in a cluster area can be derived.

Having described the model and method of estimating microcellular capacity, the technique can now be summarised in two components:

- Input system parameters
 - 1) Modulation Schemes
 - 2) BER requirement
 - 3) Outage probability
 - 4) Frequency Band
- Estimation Engine
 - 1) Deterministic Propagation Model
 - Transmitter and Receiver power
 - Building Database
 - Antenna Height and antenna Pattern
 - 2) Estimation Techniques

In comparison to the capacity assessment model developed by [1], this method greatly reduces the number of assumptions that has to be made, instead the most important parameters are produced by propagation analysis. The technique also takes into account the effect of modulation and carrier frequency. This will allow the

suitability of higher level modulation schemes and higher carrier frequencies to be investigated in a microcellular network.

Propagation pathloss data obtained from a ray tracing model can provide useful information about a particular site. Often transmission power can be adjusted to control the cell radii in a microcellular system. The following diagram is a simulation result showing the relationship between the cell radii and transmission power, the antenna pattern is omni-directional.

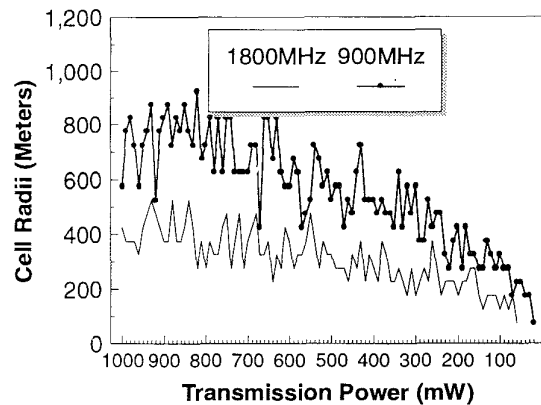


Figure 6. Transmission Power Control on Cell Radii in a Microcellular environment

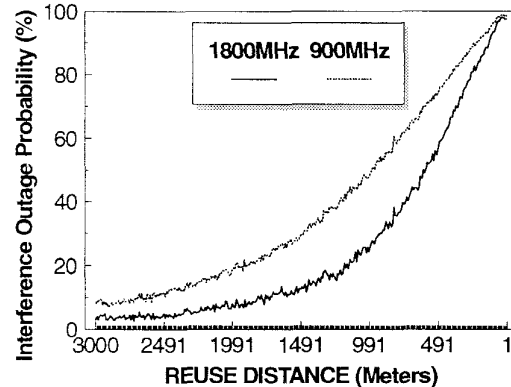


Figure 7. Simulated Result of Cochannel Interference Outage Probability

It is quite clear that lower transmission power can reduce cell radii, it is also interesting to note in the diagram that the achieved cell radii between the two frequency bands (900MHz, 1800MHz) can be minor when the transmission power is reduced to a certain level. Using the 1800 MHz frequency band has a clear advantage in reducing the reuse

distance for a given cochannel interference level. This is clearly shown in the results of Fig.

Fig. 8 shows a numerical relationship between the cochannel outage probability and the carrier to interference ratio. Obviously, the larger the reuse distance, the lower the carrier to interference required to achieve the same cochannel outage probability. The simulated carrier frequency is 900MHz, the transmission power is 10mW.

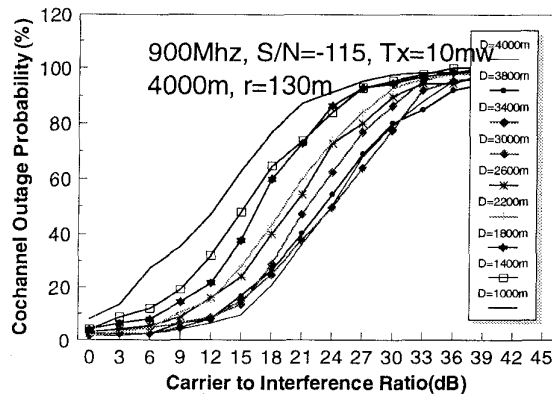


Figure 8. Trade off between Carrier to Interference Ratio and Reuse Distance

In digital communication, base stations often have more sensitive reception which can effectively eliminate the interference caused by the cochannel mobile users. Therefore, the cochannel interference encountered in this evaluation technique only takes into account the cochannel base stations down link interference, the interference caused by the mobile users has been neglected.

Ray tracing propagation models offer a slower but more accurate method for coverage prediction, improvements can also be made so that a fast prediction propagation model is developed to accommodate the capacity estimation process.

VI. CONCLUSIONS

This paper has provided a detailed description of a new capacity assessment method for microcellular systems. The developed model is based on radio propagation in a particular microcellular environment. The intention is to reduce the number of assumptions that has to be made in system simulation so that a more accurate system capacity estimate can be achieved.

There are many factors that limit the system capacity. The developed model in this paper has numerically displayed many of these complicated relationships. The proposed model makes use of transmit powers, antenna radiation

patterns, signal and interference thresholds, outage probabilities and geographical databases in the calculation of system capacity. The use of such a model will allow the influence of urban shielding and higher level modulation schemes to be fully analysed for microcellular networks.

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